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Tunable Filter Structure – Analysis and Design

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1. Introduction

A simple filter application of a new efficient hybrid method is presented in this paper. The method combines the discrete finite difference method in frequency domain (FDFD) with analytical mode matching (MM) technique and orthogonal expansion method. The procedure allows for the analysis of electromagnetic wave scattering by cylindrical objects with arbitrary cross-section located within the rectangular waveguide junction. The analyzed structures are the constructive elements of a direct-coupled resonators filter being under investigation. The size and location of the posts in a waveguide junction can be optimized to obtain the required frequency response characteristic of the filter. Moreover, an inhomogeneous shape of the investigated objects allows one to utilize them as tuning elements to correct any inaccuracies created during fabrication by means of their simple rotation.

Filters are widely used components in modern microwave communication systems. Since the modern communication develop rapidly the spectrum is becoming more and more crowded, and the requirements for more sophisticated filters are increasing. Nowadays filters should be compact, have low loss, high selectivity, high power-handling, should be capable of being manufactured in a great amount at low cost. In literature one has met many different filtering structures such as filters employing direct-coupled microwave resonators of various shapes [1]-[4], combline filters or dual-mode filters [5]-[7]. In order to meet the above mentioned requirements a high precision of manufacture is required. This on the other hand contradicts the low cost requirement. Here we propose the approach of utilizing the resonators with arbitrary cross-section to both design the filter and tune it after manufacturing in limited precision. The validity of the presented approach is verified via commercial software QuickWave 3D (FDTD) [8] and own measurements of the fabricated structure.

2. Theory

The calculations of the structure under investigation were performed utilizing the authors' hybrid (FDFD-MM) method [9] for the analysis of electromagnetic wave scattering by cylindrical objects with arbitrary geometries. The analysis of the filter structure is conducted by cascading several unit cells being the single post located arbitrarily within the junction (see Fig 1a). The posts in a single unit cell are assumed to be metallic and invariant along the height of the junction. The analysis in the cell is divided into two regions of investigation. The first region is a cylindrical area of circular cross-section which surrounds closely the isolated inhomogeneous object and the second region is the cylindrical area of circular cross-section of radius R (see Fig. 1b). The scattering nature of each isolated post is described, in the procedure, by its isolated T-matrix which relates the unknown coefficients of the scattered fields with the unknown coefficients of the incident fields (see Fig. 1c). The elements of the T-matrix are obtained by applying the proper continuity conditions on the surface of the scatterer, and depend on the particles size, shape, composition and orientation, but not on the nature of the incident or scattered fields. In our procedure the values of the isolated T-matrix are obtained with the use of FDFD method and the expressions for its elements are detailed in [9]. This procedure is the developed version of the method described in [10] and allows for the fast calculation of the multimodal scattering matrix of the junction.

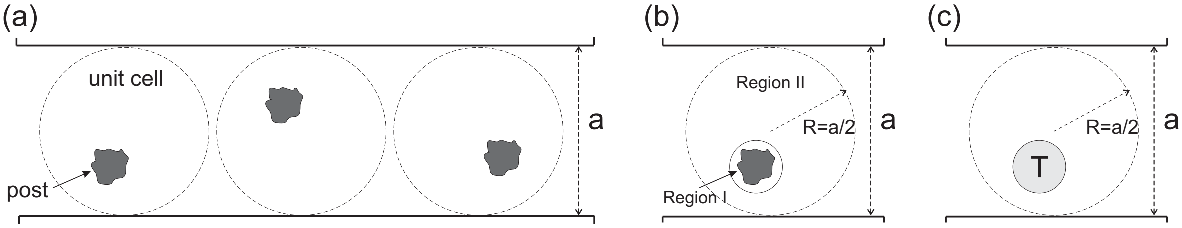

Figure 1: (a) Waveguide junction with several investigated posts; (b) single unit cell and the investigated regions; (c) T-matrix representation of the post in waveguide junction

In the cascade filters with several posts their dimensions and shift have influence on the coupling between the filter resonators. These parameters can be established for the particular type of filter during synthesis and optimization process. The posts with inhomogeneous cross-section, as distinct from common cylinders, or inductive and capacitive irises and stubs, enable one to vary the frequency response by their rotation. This effect permits one to tune the structure to the demanded frequency. In consequence one can compensate for material defects and improper dimensions or other mechanical inaccuracies created during fabrication of the structure. The other advantage of using the proposed shape of resonators in the filter structures is that there is no need to introduce additional tuning elements which would require some design modifications.

2. Simulations and Results

An example of the filter structure employing rectangular metallic posts was analyzed and manufactured for verification purposes. The experiment was performed using the Wiltron 37269A network analyzer. The fabricated models of the filter were not manufactured as optimal structures. The precision used during the fabrication process and also the mechanical errors prevented the posts used in the manufactured filters from being identical. Moreover, there were no additional technical adjustments made such as waveguide polishing and silver plating to increase the quality factor of the filter. The aim was to manufacture the structure with relatively low cost and try to utilize the tuning possibilities of the posts.

The investigated filter application is a four-section direct-coupled resonator passband chebyshev filters with a 25 dB return loss designed in WR-90 waveguide. The assumed bandwidth was 170 MHz with central frequency of 10 GHz. A schematic representation of the filter is presented in Fig. 2a.

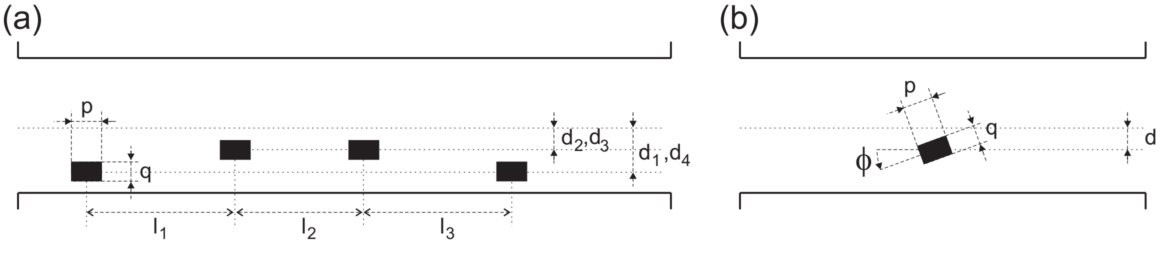

Figure 2: (a) schematic representation of the filter; (b) single rotated post in waveguide junction

The simulated frequency responses of the designed filter along with its dimensions are presented in Fig. 3a. The preliminary angle of posts rotation (see Fig 2b) in the designed filter was assumed to be zero. Assuming the fabrication precision of the structure to be 0.05 mm the calculated initial frequency responses of the filter are depicted in Fig 3b. As can be seen from the results the parameters of the structure with the distorted dimensions does not meet the designed values and are not satisfactory. As the rotation of the post has the influence on the resonance frequency, it can be used in cascade filter structures to introduce slight adjustments to the filter frequency response. For the fixed posts location in the filter structure a virtual experiment was performed which involved tuning the filter by changing the rotation angles of the posts. The result of this experiment is illustrated in Fig. 3c. As can be observed for the assumed fabrication precision in the presented example the designed goal was achieved with the use of this procedure.

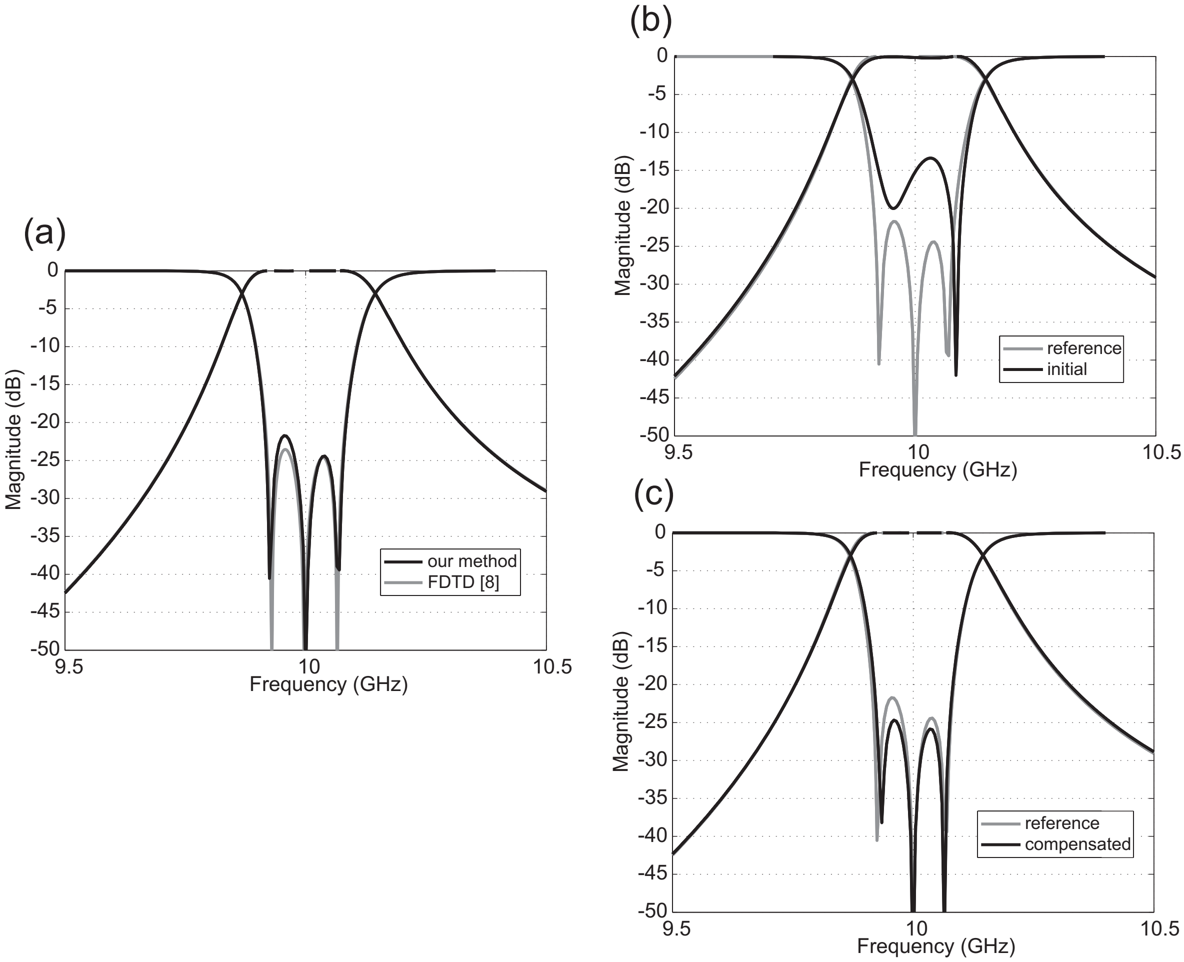

Figure 3: Simulated frequency responses of the filter with rectangular posts from Fig. 2; (a) designed model: p=8mm, q=2mm, $l_1=l_3$=22.19mm, l_2=24.11mm, $d_1=d_4$=3.94mm, $d_2=d_3$=0.52mm; (b) designed model with assumed precision of manufecture: p=8mm, q=2mm, l_1=22.20mm, l_2=24.07mm, l_3=22.22mm, d_1=3.98mm, d_2=0.53mm, d_3=0.49mm, d_4=3.96mm; (c) compensated model by post rotation angles ($\phi_1= 1°$, $\phi_2= -2.8°$, $\phi_3= 2.8°$, $\phi_4= -1°$) with dimension from (b)

The investigated filter structure was manufactured for the verification purposes. A photograph of the manufactured filter is presented in Fig 4a. The frequency responses of the designed filter and the fabricated model before and after tuning process are presented in Fig. 4b. As can be seen the preliminary fabricated model with the post orientation identical to the designed filter did not give satisfactory agreement with the designed parameters. However, only slight corrections made by rotation of the post were needed to obtain the demanded shape of the frequency response characteristics. Despite the small discrepancies between the designed and measured patterns, the obtained results are more then satisfactory and, thanks to tuning ability provided by the applied rectangular posts, the design goal was accomplished proving the correctness of the approach.

3. Conclusions

A filter application consisting of tunable rectangular posts have been presented. Due to the inhomogeneity of the post geometry their rotation have influence on the frequency responses of the waveguide junction and they can be utilized in filter structures both as resonators and tuning elements. The tuning ability of the presented forms gave satisfactory results which was verified by measurements. The presented approach can be used to tune the filter structures which are manufactured with low cost due to low precision of fabrication process.

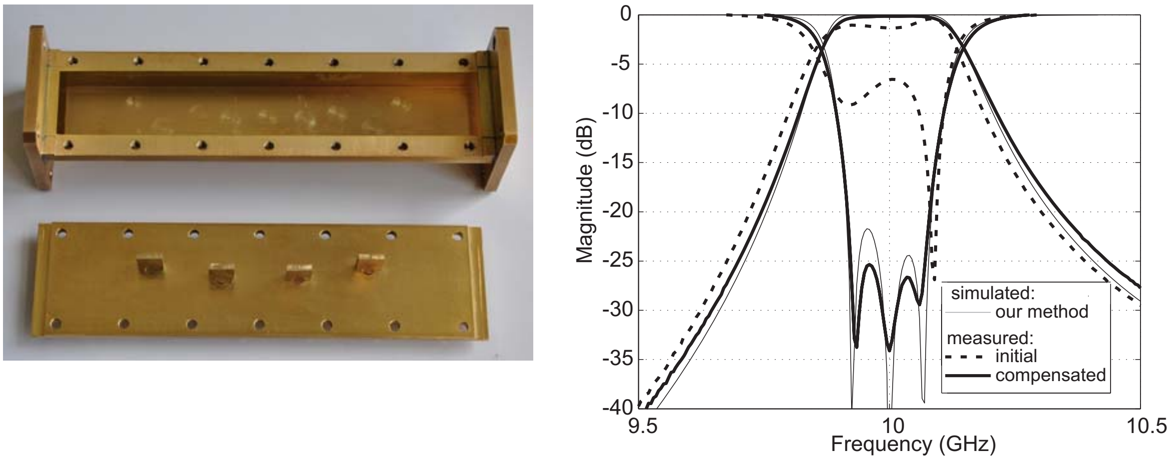

Figure 4: Photograph of the manufactured filter and its measured frequency responses

Acknowledgments

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